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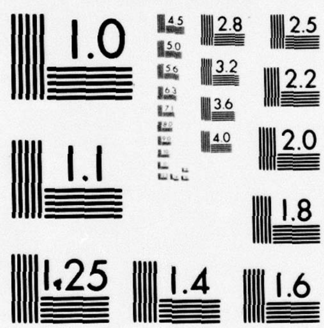

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USAARL REPORT NO. 79-14

LEVEL ~~II~~

A DIRECT MEASURE OF CRT IMAGE QUALITY

By
Robert W. Verona
Harry L. Task
Victor C. Arnold
James H. Brindle

HUMAN TOLERANCE AND SURVIVABILITY DIVISION
Sensory Physiology

September 1979

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
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20. ABSTRACT:

This paper describes a direct measuring technique for determining the image quality of raster-scanned cathode-ray tube (CRT) displays. This technique is based on the Modulation Transfer Function (MTF) theory and human visual psychophysical data. The rationale for the technique is discussed from a theoretical as well as functional viewpoint. The instrumentation necessary to obtain these measures in manual and automatic modes is discussed. Data obtained using this measurement technique are analyzed and compared with the theoretical performance of the displays. The image quality of new CRT displays procured for the U.S. Army's Advanced Attack Helicopter is being specified and tested using this direct measuring technique.

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Dr. Harry L. Task is currently with the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. Victor C. Arnold is currently with Honeywell, Incorporated, Minneapolis, Minnesota.

Mr. James H. Brindle is currently with the U.S. Army Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia.

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INTRODUCTION

Advances in electronic display technology have not yet changed the primacy of the cathode-ray tube (CRT) in the area of video information displays. Yet, a comprehensive basis for specifying television display image quality which relates to human operator performance parameters has not evolved even though numerous studies have investigated various facets of this specification problem during the past 30 years.

This specification problem is directly related to the lack of standardization in display performance metrics. Currently, no universally acceptable technique exists for analyzing television display system quality. Each manufacturer establishes his own test, measurement, and evaluation procedures.

The lack of standardization in measurement techniques makes it virtually impossible to establish comprehensive performance specifications. Presumably, television display manufacturers publish specifications so prospective buyers can evaluate this data before selecting a particular unit for their needs. But, it is difficult to find a common denominator so that one can compare units built by various manufacturers on the basis of performance.

Many techniques were tried during the late 1960's and early 1970's to measure the image quality of the miniature CRT's. In the mid 1970's a new technique was developed at the Aerospace Medical Research Laboratory (AMRL), Wright-Patterson Air Force Base (Task, Verona 1976). The U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, U.S. Army Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia, and Honeywell, Inc., have continued to use and refine the techniques developed at AMRL. The evolved procedures and caveats for applying the measuring technique to miniature as well as panel-mounted CRT displays are presented in detail.

BACKGROUND

The resolution of optical elements has been measured for years by means of two-dimensional bar patterns with various spacings and angular arrangements. The optical element under investigation forms an image of the bar pattern, and the observer subjectively determines the limiting resolution from the smallest set of bars he can resolve. With this type of test, it is possible to determine only a subjective maximum resolution. This resolution measure provides information about only a single spatial frequency. How the display operates at other spatial frequencies is not determined. Also, there is too much variability in this method of measurement for it to be used as a basis for setting specifications. As the observer changes, so does the subjective maximum resolution value.

The U.S. Air Force (USAF), National Bureau of Standards (NBS), Electronic Industries Association (EIA), and other groups interested in finding a solution to this measurement problem developed several different types of resolution charts in an effort to conduct more reliable tests. The EIA Resolution Chart (Institute of Radio Engineers 1961) is currently the most popular chart used for making a subjective evaluation of a television system's performance.

While the controversy about the best type of resolution chart to become a standard was going on, Otto H. Schade (1954), an electrical engineer at RCA, introduced a new approach to solving the problem of optical system evaluation. Schade was working in the area of communications and was intent on improving the response capabilities of television systems. Schade is recognized as the individual responsible for the method of electro-optical (E-O) system analysis called "Sine-Wave Testing." This method has led to what we now call the "Modulation Transfer Function" (MTF) analysis.

Schade wanted to optimize the complete TV system from camera to display. From electrical systems analysis he knew he could study the response of electrical elements such as amplifiers by either of two methods: first, transient response to rectangular pulse input, or second, amplitude and phase response to variable frequency, constant amplitude sine-wave inputs. The transient analysis is more difficult to use experimentally. Schade reasoned he should be able to analyze optical elements with techniques similar to those he had applied to electronic elements. The variations in intensity with angle as seen by a lens correspond to the variations in voltage with temporal frequency as seen on an oscilloscope. The variations in intensity in the former case is a function of frequency too, spatial frequency.

The concept of spatial frequency is fundamental to the understanding of MTF analysis. Spatial frequencies either in a test object or in the image of the object formed by the system are expressed in units of cycles or lines per unit distance. Spatial frequencies are thus analogous to the familiar temporal frequencies but are expressed in units of cycles per unit length.

Schade and his contemporaries investigated the transfer function of the entire electro-optical system. The measurement techniques developed in this paper apply only to the television display, the device which interfaces part of the E-O system with the human operator.

The need for both system and component performance measures exists. When purchasing a packaged E-O system, a judgment of the quality of a system is usually made on the basis of the system transfer function--its capability of transferring spatial information from sensor to display. When assembling an E-O system from components or replacing components in a packaged system, the response of the individual components must be known since each component may significantly affect the resultant system performance. A poor choice of a single component can have a devastating effect on the overall system performance. By the same rationale, using a more expensive component with performance far beyond that of the other components may not significantly improve the system performance at least from a cost effective viewpoint. The E-O system response may be obtained by a point-to-point multiplication of the component transfer functions (Figure 1).

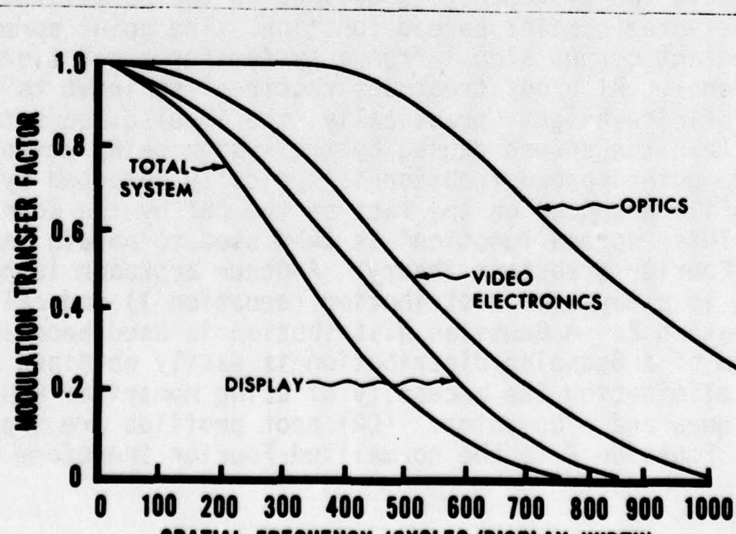


Figure 1. Resultant system response calculated from component responses.

MATERIALS AND METHODS

THE MODULATION TRANSFER FUNCTION (MTF)

In the past several years, the MTF measure of display quality has received considerable attention. The MTF has been used as a quality indicator of film and photographic systems, of optical systems and lenses, and more recently of CRT displays. Theoretically, the system MTF indicates the percent modulation that the system will pass as a function of sine-wave spatial frequency.

Since any signal (or picture) theoretically can be resolved into a set of component sine-waves, it is possible to predict how the signal (picture) will appear after passing through a system with a known MTF. Therefore, if the MTF of a system is known, the signal (picture) degradation caused by that system can be calculated. However, the system must be linear and continuous before MTF techniques can be applied. Unfortunately, CRT displays are nonlinear devices so care must be taken when applying MTF analysis to them.

There are several ways to obtain the MTF of a CRT display. Most of these methods require mathematical manipulation of empirically measured signals and assume linearity of the CRT display.

Mathematically, the system MTF is defined as the normalized Fourier transform of the system's point spread function. The point spread function is the resultant output signal from a system for a point or "narrow" impulse input signal. Rigorous treatment requires the input to be of zero width and infinite height; practically, the impulse needs to be "much narrower" than the spread caused by the system being tested. For CRT displays, the point spread function is typically obtained by measuring the spot profile produced on the face of the CRT by the scanning electron beam. This "spread function" is then used to obtain the MTF by applying the Fourier transform theory. Another approach is to assume the spot profile is a Gaussian distribution (equation 1) and calculate the MTF from equation 2. A Gaussian distribution is used because the Fourier transform of a Gaussian distribution is easily obtained in analytic form thus eliminating the necessity of using numerical Fourier transform techniques and a computer. (CRT spot profiles are typically near Gaussian.) Equation 2 is the normalized Fourier transform of equation 1.

Gaussian luminance distribution of CRT spot

$$L(x) = Ke^{-1/2(x/\sigma)^2} \tag{1}$$

where

L = luminance distribution
K = constant
x = spatial parameter (length)
σ = standard deviation of the Gaussian distribution (in same units as x)

Taking the Fourier transform of equation 1 yields the MTF

$$MTF(f) = e^{-2(\pi\sigma f)^2} \tag{2}$$

where

f = spatial frequency
σ = standard deviation of Gaussian distribution
$MTF(f)$ = modulation transfer factor

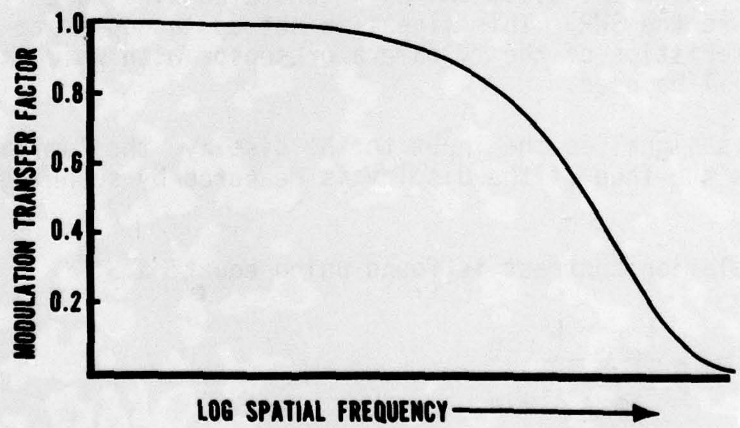


Figure 2. Typical MTF obtained from calculations based on assuming a Gaussian distribution spot profile as a point spread function.

Other methods of obtaining the MTF of a CRT display require Fourier analysis of square-wave, line or edge patterns. In each case the MTF must subsequently be calculated, assuming linearity of the display.

The direct method of obtaining the display MTF is to measure the modulation transfer of the display for sine-wave signals of various frequencies. The problem with applying this approach to CRT displays is that the input signal is electronic (measured in volts) and the output signal is photometric (measured in footlamberts). Thus, the output to input ratio (percent of modulation transfer) is not clearly defined. Typically, this problem is circumvented by using a normalization procedure, the results of which can be misleading.

DISPLAY MEASUREMENT PROCEDURES

The sine-wave response (SWR) measurement was devised to avoid the problems inherent in calculating the MTF by using the various methods described. The SWR relates the maximum modulation contrast capability of the display to spatial frequency, measured <u>directly</u> frequency by frequency. This differs from the MTF in two important respects: (1) it does not assume linearity of the CRT display, and (2) it is not a normalized function. Later in this paper the importance of these two characteristics will become more apparent.

Figure 3 shows the electronically generated sine-wave video signal used to measure the SWR. This signal is set up to duplicate the voltage level characteristics of the TV camera or sensor with which the display under test will be used.

With this signal as the input to the display, the luminance distribution across the face of the display is measured by scanning with a photometer.

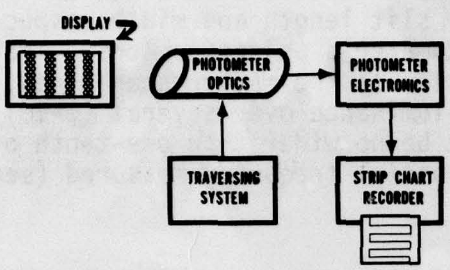
The modulation contrast is found using equation 3.

$$M_c = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \qquad (3)$$

where

M_c = modulation contrast
M_{max} = peak luminance level
L_{min} = minimum luminance level

This is repeated for several spatial frequencies until the entire SWR is obtained. Figure 4 shows a typical SWR for a high quality display.



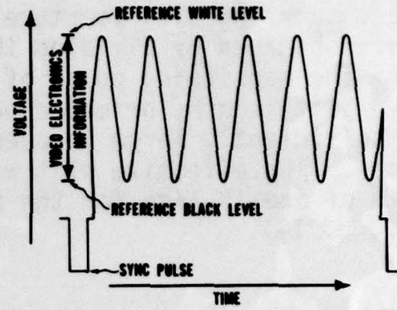
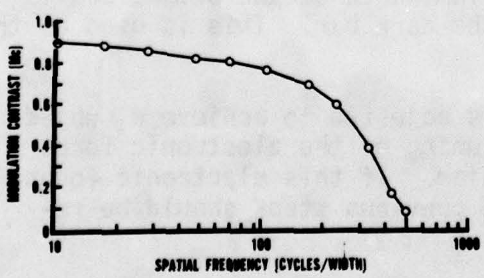


Figure 3. Electronically generated video sine-wave.

Figure 4. Typical sine-wave response (SWR) curve for a miniature CRT display.

Required equipment

Two pieces of equipment are required to make the display measurements. First, a video test signal generator capable of producing a constant amplitude sine-wave and square-wave signal, in video format, over the electronic frequencies of interest is required (see Figure 5). Second, a means of measuring the resulting luminance distribution on the display screen is needed (see Figure 6). The luminance profile can be measured using either a photometer with appropriate optics and a narrow slit aperture or it can be calculated from measurements made with a spectroradiometer. For narrow band color phosphors, such as the P-44, it may be advisable to calculate the luminance from the spectroradiometric measurements since photopic correction filters for photometers may not match the human eye's photopic response at all wavelengths in the visible spectrum.



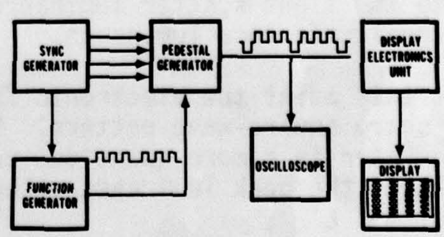


Figure 5. Equipment used to generate sine-wave and square-wave video test signals.

Figure 6. Photometric system for measuring and recording display luminance.

Several factors influence the selection of the photometer imaging optics and sampling slit aperture size. The effective slit width and length are obtained by dividing the actual slit length and width respectively by the magnifying power of the photometer's objective lens. The effective slit length, oriented perpendicular to the raster scan lines, must be sufficiently large to average the luminance over several (6-10) scan lines. The effective slit width must be no wider than one-tenth of the width of one TV line for the highest spatial frequency measured (see Figure 7, p. 14).

Display set-up procedure

Before any measurements of the display are made, the display must be properly set up. The first step in the set-up procedure is to adjust the size, aspect ratio, linearity of scan, and voltage levels according to the manufacturer's instructions and specifications. These parameters must remain constant during the analysis (some displays may require 30-60 minutes to stabilize).

The display brightness and contrast controls must be set up to provide the "best" video image. The following procedure was developed to set the controls for maximum picture contrast but without any black level clipping of the image.

A video compatible square-wave signal corresponding to a 9-15 TV line/PH (6-10 cycles/display width) pattern is applied to the display input. The brightness and contrast controls are then set to totally clip (electron beam cut-off) the lower voltage bars (reference black level of Figure 3) of the image, keeping the bright bars (reference white level) at some specified peak luminance level, such as 150 ft-L. This pattern is scanned by the slit photometer to measure the luminance profile. The luminance measured at the center of the dark bars is due totally to halation or light scatter since the electron beam is cut off for this portion of the pattern. One-half of one percent of the luminance of the bright bar is added to the light scatter luminance of the dark bar. This is used as the black level reference luminance.

At this point the electronic focus is adjusted to achieve a subjectively sharp square-wave pattern. Fine tuning of the electronic focus is done later in a more quantitative fashion. If this electronic focusing changes the peak luminance value, the previous steps should be repeated.

The ratio of the peak luminance bar to the black level reference luminance is the contrast ratio for the display. It is apparent from this process that the maximum contrast ratio obtainable is 200:1. This limitation has not proved to be a problem to date.

Using the brightness and contrast controls, the white reference is set to the specified peak luminance and the black reference is set to the minimum luminance defined by the contrast ratio for the 9-15 TV line/PH square-wave input signal. This is an iterative process of adjusting brightness then contrast to achieve the desired luminance levels.

If the transfer characteristics of the CRT (i.e., luminance versus grid to cathode voltage) and the raster cut-off voltages are known, an alternate method of set-up can be accomplished by adjusting the CRT drive and bias voltages for the desired peak luminance and contrast ratio. The constraints on the CRT drive voltage are determined from the CRT transfer curve; they are the grid to cathode voltage levels bounded between the raster cut-off and the desired peak luminance. As long as these values are not exceeded, the CRT will not normally be overdriven. The brightness and contrast controls are adjusted to simultaneously achieve a "just" active black in the dark bar areas while maintaining the maximum desired peak luminance in the reference white areas.

Thus, using either set-up procedure, the display brightness and contrast controls will have been set to achieve the maximum modulation contrast attainable for a specific peak luminance. If the controls are adjusted so the display operates into a cut-off region, the CRT image will be "black level clipped," i.e., fine detail in low luminance display areas will be indistinguishable and the modulation contrast will be inflated. If the controls are adjusted so the display operates into a saturation region, the CRT image will be "washed out," i.e., fine detail in the high luminance display areas will be indistinguishable and the modulation contrast will be diminished.

If the actual E-O sensor video is applied to the display, the peak video levels produce peak luminance and the minimum video levels produce "just" active black for low spatial frequencies. This assures maximum modulation contrast from the sensor's output to appear on the display without black level clipping. The brightness and contrast controls are now set for the Video Transfer Function (VTF) and SWR measurements.

<u>Video transfer function (VTF) measurement</u>

The VTF describes the relationship between the input video signal and the output luminance level for a relatively low (9-15 TV lines/PH or 6-10 cycles/width) spatial frequency. The VTF is measured by adjusting the amplitude of the peak video bars to the maximum sensor video output level and measuring the bar luminance as the signal level is decreased in equal voltage increments to the minimum sensor output level. The resulting luminance versus signal voltage is the VTF (see Figure 8).

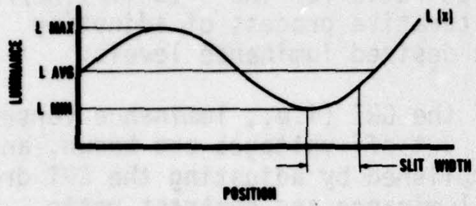


Figure 7. Relationship between effective slit width and one cycle at the highest spatial frequency sine-wave measured.

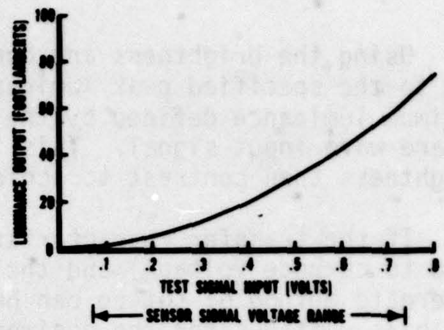


Figure 8. Typical video transfer function (VTF).

The VTF yields useful information concerning the operating point of the display. From the VTF it is possible to determine if the display has been adjusted so as to cause black level clipping of video information at low frequency levels. It is also possible to determine how linearly the display operates and to what extent, if any, the display incorporates gamma correction circuitry.

Sine-wave response (SWR) measurement

Before the SWR can be measured, the electronic focus must be finely adjusted. A video sine-wave signal at about 300 TV lines/PH (200 cycles/display width) is input to the display. The electronic focus is adjusted to obtain a maximum contrast on the CRT measured photometrically. This insures the best spot focus for the direction of the scanning beam.

The photometer scans the luminance profile on the display for several spatial frequencies and the output is recorded on a strip chart recorder. The average maximum and average minimum luminance values are then used to calculate the modulation contrast (equation 3) for each spatial frequency. The graph of modulation contrast versus spatial frequency is the SWR. A correction factor is applied to the SWR curve to compensate for the spatial frequency dependent modulation contrast degradation of the photometer caused by its finite-width scanning aperture and imaging lens MTF.

In most cases, it is convenient to use the EIA standard video formats for measuring the display's performance unless the exact E-O sensor

output video format is known. For the VTF and SWR curves to be meaningful, the video signal format used to generate them must match the format of the sensor output video.

The first question that arose after establishing this procedure was: "How repeatable is it?" To answer this question, the VTF and SWR of a miniature CRT display were measured 10 times over a period of 3 days. Before each measurement trial all controls were set to zero and then readjusted according to the previously described procedure. Based on this test it was apparent that the SWR was sufficiently reliable to be used as a measure of display quality and performance.

DEVELOPMENTAL PROCEDURES

The measurement techniques discussed so far are not sensitive to phosphor persistence. A CRT display with a long persistence phosphor may have a similar SWR and VTF as a phosphor with a medium or short persistence. The SWR and VTF may adequately describe the performance of a CRT used to display static imagery but would be dreadfully lacking in describing the performance of a CRT used to display dynamic imagery. Another technique being investigated could be used to measure the modulation contrast degradation, under dynamic conditions, caused by excessive phosphor persistence. The spatial sine-wave pattern is electronically drifted across the CRT screen at a constant velocity in front of a stationary photometer with a slit aperture. The modulation contrast values are calculated for a series of spatial frequencies for each drift velocity. This procedure generates a family of SWR curves; depicting the modulation contrast degradation at each spatial frequency as a function of drift velocity.

The instrumentation becomes more complex when the temporal as well as the spatial aspects of the CRT imagery are quantified. The temporal response of the measurement system can easily be confounded with the display's temporal response. The temporal response of the photometer and strip chart recorder must be scrutinized carefully. Insufficient integration time in the photometer will result in transients when the CRT spot is visible through the slit aperture. Slow response times in the photometer and/or chart recorder will be manifested in deflated modulation contrast values.

An integration time of about .05 to 0.1 seconds is needed in the photometer and a frequency response of greater than 30 Hz is required of the chart recorder. The photometer can easily achieve the desired integration time, but a digital processing and storage unit is substituted for the 0.5 Hz strip chart recorder. The digitizer can easily and accurately process and store the analog photometric data within the time constraints.

The dynamic measurement procedures are still being tested and refined to insure repeatability; they must also be validated to insure that it is measuring what it purports to be measuring. The results so far seem promising.

The CRT quality measurement procedures discussed in this paper are quite time consuming. In order to be acceptable as an industrial testing procedure, it must be streamlined and automated. An automated measurement system is currently being fabricated and integrated into a system which is expected to satisfy the production industrial display measurement applications. The initial set-up procedures must still be partially manual, but the data acquisition and documentation functions are performed automatically.

The heart of the new system is the Hewlett-Packard 9835 Desktop Computer. It controls, by way of its interface bus, the Hewlett-Packard Function Generator, the Gamma Scientific Spatial and Spectral Scanning Photometer/Radiometer, the Klinger Scientific Precision Positioning System, and peripheral floppy disk, impact printer, four color plotter, and CRT display terminal. This experimental system is expected to prompt, acquire, process, flag, plot, and document static and dynamic display evaluation data.

CONCLUSIONS

Implementation of the SWR evaluation technique by a major miniature CRT supplier has resulted in an improvement in the performance characteristics of CRT's delivered for a U.S. Army helmet mounted display program for the YAH-64, Advanced Attack Helicopter. This procedure has been demonstrated on 50 CRT's delivered over an 18-month period.

These improvements are a direct result of the manufacturers' ability to evaluate a CRT beyond the traditional screening for spot size, cut-off voltage, luminance, etc., and make controlled design improvements/corrections leading toward achieving specified performance requirements.

REFERENCES

Institute of Electrical and Electronics Engineers, Inc. 1961. *Video techniques: measurement of resolution of camera systems.* New York, NY: Institute of Electrical and Electronics Engineers, Inc. IEEE-Std 208-1960 (Reaff 1972).

Schade, O. H. 1954. *A new system of measuring and specifying image definition.* Washington, DC: National Bureau of Standards. NBS Circular 526.

Task, H. L. and Verona, R. W. 1976. *A new measure of television display quality relatable to observer performance.* Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory. AMRL-TR-76-73.

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Fort Monmouth, NJ 07703 (1)

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US Army Combat Surveillance &
Target Acquisition Laboratory
ATTN: DELCS-D
Fort Monmouth, NJ 07703 (1)

US Army Avionics R&D Activity
ATTN: DAVAA-O
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US Army White Sands Missile Range
Technical Library Division
White Sands Missile Range
New Mexico 88002 (1)

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LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal
Watervliet, NY 12189 (1)

US Army Research & Technology Labs
Propulsion Laboratory MS 77-5
NASA Lewis Research Center
Cleveland, OH 44135 (1)

US Army Field Artillery School
Library
Snow Hall, Room 16
Fort Sill, OK 73503 (1)

US Army
Dugway Proving Ground
Technical Library
Bldg 5330
Dugway, UT 84022 (1)

US Army Material Development &
Readiness Command
ATTN: DRCSG
5001 Eisenhower Avenue
Alexandria, VA 22333 (1)

US Army Foreign Science & Technology
Center
ATTN: DRXST-IS1
220 7th St., NE
Charlottesville, VA 22901 (1)

US Army Training & Doctrine Command
ATTN: ATCD
Fort Monroe, VA 23651 (2)

Commander
US Army Training & Doctrine Command
ATTN: Surgeon
Fort Monroe, VA 23651 (1)

US Army Research & Technology Labs
Structures Laboratory Library
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665 (1)

Commander
10th Medical Laboratory
ATTN: DEHE (Audiologist)
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Commander
US Army Natick R&D Command
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Natick, MA 01760 (1)

Commander
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ATTN: DRSTS-W
St. Louis, MO 63102 (1)

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US Army Aviation R&D Command
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PO Box 209
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Aberdeen Proving Ground, MD
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Development Command
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PO Box 209
St. Louis, MO 63166 (1)

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US Army Health Services Command
ATTN: Library
Fort Sam Houston, TX 78234 (1)

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US Army Academy of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234 (1)

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US Army Airmobility Laboratory
ATTN: Library
Fort Eustis, VA 23604 (1)

Air University Library (AUL/LSE)
Maxwell AFB, AL 36112 (1)

US Air Force
Flight Test Center
Technical Library, Stop 238
Edwards AFB, CA 93523 (1)

US Air Force
Armament Development & Test Center
Technical Library
Eglin AFB, FL 32542 (1)

US Air Force Institute of
Technology (AFIT/LDE)
Bldg 640, Area B
Wright-Patterson AFB, OH 45433 (1)

US Air Force
Aerospace Medical Division
School of Aerospace Medicine
Aeromedical Library/TSK-4
Brooks AFB, TX 78235 (1)

Director of Professional Services
Office of The Surgeon General
Department of the Air Force
Washington, DC 20314 (1)

Human Engineering Division
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Laboratory
ATTN: Technical Librarian
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OH 45433 (1)

US Navy
Naval Weapons Center
Technical Library Division
Code 2333
China Lake, CA 93555 (1)

US Navy
Naval Aerospace Medical Institute
Library
Bldg 1953, Code 012
Pensacola, FL 32508 (1)

US Navy
Naval Submarine Medical Research Lab
Medical Library, Naval Submarine Base
Box 900
Groton, CT 06340 (1)

Director
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Naval Supply Center, Bldg 844
Oakland, CA 94625 (1)

Naval Air Systems Command
ATTN: V/STOL Aircraft Branch
Department of the Navy
Washington, DC 20360 (1)

US Navy
Naval Research Laboratory Library
Code 1433
Washington, DC 20375 (1)

US Navy
Naval Air Development Center
Technical Information Division
Technical Support Department
Warminster, PA 18974 (1)

Human Factors Engineering Division
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Naval Research Laboratory Library
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